Placement of Mobile Base Stations in Wireless Sensor Networks using Vector Dominating Set

N.Santhana Krishna, Researcher Scholar,
AJK College of Arts and Science, Tamilnadu, India
santhanakrishna@ajkcas.com

Dr. K.Pradeepa, Dean-Computer Science,
AJK College of Arts and Science, Tamilnadu, India
pradeepa.kmk@gmail.com

ABSTRACT - Numerous research works has focused on the positioning multiple mobile sinks in the network area to improvise the lifetime of wireless sensor network. The experimental results of the research works clearly indicates that the lifetime of the network will be increased several folds on exploiting multiple mobile sinks in the network rather than static sinks. The proposed paper employs multiple mobile sinks to increase the lifetime of network. The research work focuses on finding the best energy rich locations for placing multiple mobile sinks in a way it delays the expiry of one hop sensor nodes. The paper contributes an Integer Linear Programming (ILP) formulation for the positioning of mobile sinks. In an attempt to find the best location to place the mobile sinks, the paper discretizes the solution space as a replacement for the entire network. The energy rich positions for positioning the mobile sinks are found through the solution ofthe ILP formulation. As an alternative of running the ILP on a continuous search space, the solution space is discretized and ILP is implemented on the discretized space. Experimental results indicate that the proposed ILP model maximizes the network lifetime to a great extent in comparison with the static sink method.

KEYWORDS: Wireless Sensor Network, WSN, Mobile sinks, Network Lifetime, Discretization, Inter Liner Programming, and Cluster Heads

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1. INTRODUCTION

Wireless sensor network (WSN) denotes to a collection of spatially spread and devoted sensors for monitoring and collecting the physical conditions related to environment and consolidating the composed data at a centralized location. WSNs quantify environmental parameters like temperature, humidity, pressure, moisture, pollution levels, wind, and so on. The data collected from the sensor nodes is collected and processed by the cluster heads and forwarded to base stations.The energy constrained sensor nodeslevynumerous challenges that mustbe dealt to achieve maximum benefits [1]. In this paper we are using multiple sinks which are positioned at optimal locations by using ILP model. Numerous previous research papers have experimented abundant with static, single and multiple mobile sinks which are positioned at various locations on like center of the network, periphery and at random energy rich spots. In conventional static sink model where the sink is positioned at the center of the network, sensor nodes that are in the first corona of the sink deplete their energy level soon resulting in fast demise of the network [2].To cope up with this shortcoming, researchers' instigated works on mobile sinks where the sinks will be relocated at regular intervals to minimize the formation of hotspot. [17]

The proposed research work has utilized multiple mobile sinks to increase the lifetime of the network. The optimal locations for placing the sinks are obtained through running an ILP model. The novelty that is focused on the paper is that the authors have considered discretized solution space rather than a continuous one. The solution space is discretized by using the concept of Vector dominating sets from graph theory. The concept is used to convert the solution space in to a finite set. At the beginning of each round the solution space is discretized and ILP is run on the finite set to obtain the energy rich zone for placing the multiple mobile sinks. Sinks will stay at the same position till the end of one round and subsequent relocation will be initiated at the commencement of the next round, and so on, till the end of network lifetime. The novelty of the paper lies in the deploying the concept of vector dominating set for conversion of solution space in to a finite set. The rest of our paper is organized as follows. Thorough literature survey is discussed in Section 2. In Section 3 we explain about the network model, Section 4 explain the concept of using Vector dominating Set(VDS) for the purpose of discretization. ILP model and its formulation are explained in Section 5. The simulation experiments and the results are showcased. The experiment results showcase a good improvement in network lifetime when compared to the existing algorithms. Simulation experiments are done with varying networks sizes (100 and 200 nodes) and the results are compared with existing algorithms.

2. RELATED WORK

Utilization of multiple sinks to increase the network lifetime has attracted a lot of researchers. Mobile sinks increases the network lifetime in multifold when compared to the static sink category. In[3]the solution space for base station placement is converted to a finite set. The proposed work in [3] exposed that for an optimality of $(1 - \varepsilon)$, the infinite solution space is converted to a finite solution space by using several constructive steps (i.e., discretization of energy cost through a geometric sequence, division of a disk into a finite number of subareas, and representation of each subarea with fictitious cost point (FCP)). A newprocedure is by created by the authors for transforming the solution space from an infinite set to finite one thereforechanging the integer linear programming as discrete rather than a continuous one.

Saad et al. [4] proposed a new algorithm which determines the trajectory for the mobile bases station which follows the trajectory to visit a group of cluster heads for data collection. The work group a set of sensor nodes to form clusters and an energy rich node will be selected as cluster head. The algorithm also confirms that number of hops for each sensor node to the cluster head is no more than two hops. The cluster head is responsible for collection and buffering of sensed data. When the base station reaches the one hop proximity of the cluster head, the data is communicated to the base station by the cluster head. The drawback with the proposed work is that it does not cover the delay involved with base station in data collection. The authors of [5]extended their contribution to another work discussed in [6] and location of the cluster head is opted as the rendezvous point for the base station. The algorithm proposed in [6] is an event based data gathering with the base station visiting the cluster head only when it generates data.

The work of [7] discusses about exploiting multiple mobile sinks moving in a predetermined trajectory. The author has divided the network in to hexagonal tiles and the sinks are made to move along the hexagonal tiling for data collection. The paper exploits both constant as well as adaptive stopping time for the sinks. In adaptive stopping a new Linear Programming Problem is formulated which finds the optimum stopping time for sinks. Simulation experiments showcased an improvement in network lifetime when compared with static sink category.

Data collection through bounded hop count is discussed in the works [8, 9]. The authors of [8] proposed a new polling-based mobile gathering approach termed bounded relay hop mobile data gathering (BRH-MDG)which is formulated as an optimization problem. Subsections of sensor nodes were designated as polling points that buffer locally aggregated data and transfers the data to the mobile base station when it reaches the proximity. The authors also guarantee that the sensor associated with the polling points will have an efficient packet bounded within a given number of hops. In another work[9] Chen et al quoting the shortcoming of BRH-MDG algorithm , that it did not carefully analyze and optimize the energy consumption of the entire network, proposed another mathematical model with a novel algorithm called EEBRHM. Theexperimental results display that under the evidence of bounded relay hop, compared with BRH-MDG, EEBRHM can extend the networks lifetime by 730%

Similarly in [10], Pradeepa et al discussed proposed a new Integer Linear Programming (ILP) model for positioning multiple base stations in a network. The candidate locations for placement of base station are obtained through the ILP model. Apart from providing ILP formulation for positioning multiple base stations, the authors also proposed a heuristic protocol to find the optimal location for lacing the base station. Simulation experiments show good improvement in terms of network lifetime.

Apportioning sensing area into subareas is discussed in [11, 12]. Chen et al. [11]proposed a lifetime optimization algorithm limited by data transmission delay and hops (LOA_DH) for mobile sink-based wireless sensor networks.. In LOA_DH, few important constraints are examined, and an optimization model is suggested. The authors has used Maximum capacity path routing algorithm to calculate the energy consumption of communication and a genetic algorithm which adapts individuals to meet all constraints is used to solve the optimization model. The proposed algorithm identifies the optimal sink sojourn time and location which will maximize the sensor network lifetime.Experimental results show that the proposed optimization model improves network lifetime and reduces average amount of node discarded data and average energy consumption of nodes.In

In [12] the authors have proposed rendezvous point (RP)-based delay bound path design for the mobile sink. In the proposed method, the target area is partitioned into hexagonal cells whose centers are considered as the potential positions of RPs. These potential positions are minimized on the basis of several network parameters to select minimum number of RPs to form the delay bound path. Extensive simulations were carried over the proposed algorithm to compare its results with some existing algorithm using several performance metrics like hop count, network lifetime and many more to prove its effectiveness.

The proposed algorithm in [13] is called the bounded relay combine-TSP-reduce (BR-CTR). The bounded relay combine-TSP-reduce algorithm visits the convergence area of sensors' communication ranges to minimize the number of sojourn points. The BR-CTR procedure is combined with a path adjustment mechanism, which can further shorten the planned traveling path effectively. Simulation results shows that the proposed algorithm has good performance in comparison with the existing single hop and multi hop mobile data gathering algorithms.The goal of the paper [14] is to decrease the data transmission distances of the sensor nodes by using the tree structure and multi-hop ideas. Based on the position of mobile sink, the distances between the sensor nodes, and the residual energy of each sensor node, the proposed scheme makes an efficient decision for creating the routing structure. The energy consumption is reduced and the lifetime is extended for the sensor nodes by balancing the network load. Simulation results demonstrate the superior performance of the proposed scheme and its ability to strike the appropriate performance in the energy consumption, network lifetime, throughput, and transmission overhead. In addition, suitable delay time and number of retransmission messages can be achieved for the WSNs with mobile sink.

The main goal of paper [15] is to employ the concepts of tree structure and multihops to reduce the data transmission distances of the sensor nodes. Decisions on creating the routing structure are done based on the position of mobile sink, the distances between the individual sensor nodes, and the residual energy of each sensor node. The lifetime of the network is enhanced by reducing the energy consumption and balancing the network load. Experimental results demonstrate significant performance of the proposed scheme and its capacity to achieve the proper performance in the energy consumption, network lifetime, throughput, and transmission overhead.

The work in [16] points out that the influence of node density is important, and this factor is not sufficiently addressed in many research works.As a consequence , several schemes to compute hop count imply geographic routing, even if they aim to consider the shortest path routes. Therefore, the authors of [16] proposed a novel technique for calculating hop count. They consider the hop count when the network nodes are uniformly positioned and the shortest path between the source and the destination is selected. The analytical model is verified by simulation. Simulation results indicate a very good enhancement in network performance over the other conventional scheme. All the past research works has focused on improvising the network lifetime and network performance by minimizing the energy consumption of each node.

2.1 Contributions of the Paper

The research work proposes an Integer Linear Programming formulation for positioning multiple mobile base stations across the sensor network. The solution space for the ILP formulation is discretized by employing the concept of Vector Dominating Set from graph theory. Focus is also given to counter that the discretization of the solution space is not affecting the quality parameter of our final output. The authors categorize the contributions of our papers as follows.

1. A procedure employing the concept of Vector Dominating Set (VDS) is used to make the solution space for the Integer Linear Programming formulation as a finite set.
2. It is proved using two theorems that the algorithm used for discretization is an approximation algorithm for finding the vector dominating set and the discretized set will provide a complete cover over the entire network
3. The research work recommend an Integer Linear Programming formulation which

increases the network lifetime by maximizing the minimum residual energy

3. NETWORK MODEL AND PROBLEM DEFINITION

The network model incorporates a set of randomly deployed sensor nodes (N) and ‘M’ number of mobile base stations. The sensor nodes are assumed to be static and their task is to monitor the sensing field to meet their requirements. The base stations are assumed to be movable and can be found in different arbitrary places during network operation. A particular sensor node “i” is assumed to generate data at a rate r_i and transfers the data to base station by means of multihop communication. The structure of the network is demonstrated as a graph G= (N, E) where N is the set of all sensor nodes which represents the vertices of a graph and E is the set of all edges. An edge will be appearing between two sensors X and Y if both of them lie within the communication radius of each other. Neighboring nodes of a particular sensor node is called is termed as adjacent nodes and let it be N_i. The network model is summarized as follows

- The type of network is presumed to be a heterogeneous. Sensor nodes are assumed to be immovable and they use bidirectional and error free communication model..
- Base stations are supposed to be moveable.
- The base station can generously travel from one sojourn position to another.
- For analytical simplicity the time taken by the base station to travel from one sojourn point to another is considered to be negligible.
- Data transmission and response are considered to be the major energy consuming activities without loss of generality
- The buffer size of the sensor node is unbounded but the node is energy conscious (i.e. Limited battery power)
- Sensors communicate with the base station through multi – hop communication.\The problem statement can be defined as follows:
-

“The lifetime of the sensor networks is defined as set of rounds of same duration. At the commencement of each round, M mobile base station has to be placed at optimal positions which will maximize he sensor network lifetime by maximizing the minimum residual energy at the termination of each single round.

The novel idea considered in the proposed research work is the discretization of solution space by using the concept of Edge Dominating Set from graph theory for the placement of base station. Most of the previous works have focused on placing the base station on a continuous solution space. Only few have concentrated on discrete optimization for the base station placement problem. The first challenge in our placement problem is converting the infinite solution space to finite without curbing the quality and quantity parameters of our final solution
A vertex cover of an undirected graph is a subset of its vertices such that for every edge (u, v) of the graph, either ‘u’ or ‘v’ is in the vertex cover. Although the name is Vertex Cover, the set covers all edges of the given graph. Given an undirected graph, the vertex cover problem is to find minimum size vertex cover.

A vertex cover having the smallest possible number of vertices for a given graph is known as a minimum vertex cover. There is no polynomial time algorithm available for finding the minimum vertex cover and finding a minimum vertex cover is a classical optimization problem in computer science . Minimum vertex cover problem is a classic example of an NP-hard optimization problem that has an approximation algorithm

The following approximation algorithm is used to find the minimum vertex cover. The following approximation algorithm is efficient in extracting approximate solutions to minimum vertex cover problems . Approximation algorithms logically arise in the branch of theoretical computer science as a significance of the generally believed P ≠ NP conjecture. Under this conjecture, a wide class of optimization problems cannot be solved exactly in polynomial time.

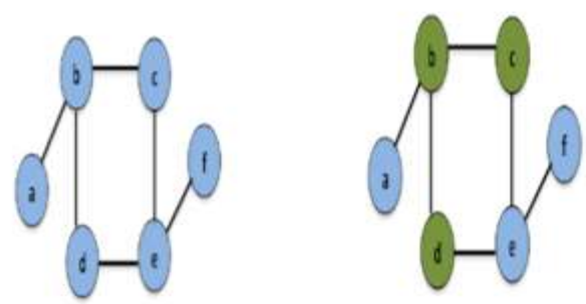

Figure 1: A graph and its Vector Dominating Sets

Procedure Vertex_Cover (Graph G, V, E)

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// G is the input graph

//V is the set of vertices in Graph G

// E is the set of Edges in Graph G

1. Let G be the graph

2. Let V be the set of all edges of the given graph G

3. Let E be the set of all edges of the given graph G

4. Initialize an empty Set VC {}

5. Do the following while E is not empty

a) Pick an arbitrary edge (u, v) from set E and add 'u' and 'v' to VC

b) Remove all edges from E which are either incident on u or v.

6. Return result

}

Theorem 1 the above algorithm is a factor 2 approximation to Vertex-Cover.

Proof: What Algorithm 1 finds in the end is a matching (a set of edges no two of which share an endpoint) that is "maximal" (meaning that you can't add any more edges to it and keep it a matching). This means if both endpoints of those edges are considered, it yields a vertex cover. In particular, if the algorithm picked k edges, the vertex cover found has size 2k. But, any vertex cover must have size at least k since it needs to have at least one endpoint of each of these edges, and since these edges don't touch, these are k different vertices. So the algorithm is a 2-approximation as desired.

Theorem 2: Set VC incorporating the vertices of vertex cover offers a full graph cover of the network.

Proof: As per the definition of vertex cover of undirected graphs is a subset of its vertices such that for every edge (u, v) of the graph, either 'u' or 'v' is in the vertex cover. It is evident from the definition of vertex cover that set of vertices except the vertices in VC will be adjacent to any one of the vertex in the set VC. Thereby, retrieving a vertex cover set will provide a complete graph cover to the network. The set VC can be considered as a discretized set and considering those vertex geographical positions is equivalent to considering the entire network without compromising on the quality parameter of our final solution

4. ILP FORMULATION

The above procedure yields a set (VC) which contains a set of points across the network. The Integer Linear Programming model works on the set of points in VC which will yield the optimal sojourn points for the mobile base stations. This way the research work reduce the number of candidate points to be considered for base station placement as a finite set rather than running the ILP model on an infinite search space.The following constants and variables are assumed to support the formulation of ILP.

Constants and Variables:

The following table lists the constants and variables used in the ILP formulation

E_{Tr}	Energy spent by a sensor node for transmitting one packet of data
E_R	Energy spent by a sensor node for receiving one packet of data
E_i	Residual energy of a particular sensor node n_i.
g_i	Data generation rate of a particular sensor node n_i
N	Total number of sensor nodes.
M	Total number of base stations
T	Total number of points in the set VC
g_{ij}	Data flow rate from a sensor node n_i to sensor node n_j
N(i)	Adjacent sensor nodes of a particular sensor node i
E_{min}	Minimum residual energy of a sensor node at the end of a round
loc_j	This is binary variable which will hold only values {0, 1}.This will be set to 1 if the mobile base station is located at point j, else it will hold 0

Table 2: List of Constants and Variables

The purpose of formulating the ILP is to maximize the sensor network lifetime by minimizing the energy consumption thereby increasing the residual energy. The ILP formulation maximizes the minimum residual energy at the end of each round. Constraint (1) declares that for any particular sensor node 'i', the overallcount of number of received packets from a node k and number of packets generated by itshould be equalto the total number of outgoing packets.

$$\sum_{k\epsilon N(i)} g_{ki} + g_i = \sum_{j\epsilon N(i)} g_{ij} \quad 0 \le i \le N \qquad (1)$$

Constraint (2) warranties the minimum residual energy requirement. The energy spent by the sensor node for transmitting and receiving the packet should consume energy in such a way that the balance energy should always be higher the minimum energy requirement.

$$E_i - \left(E_{Tr} \sum_{j\epsilon N(i)} g_{ij} + E_R \sum_{k\epsilon N(i)} g_{ki}\right) \ge E_{min}, 0 \le i \le N \quad (2)$$

Constraint (3)checks the non – negativityof the minimum energy available. It states that the minimum energy of a sensor node should always be larger than or equal to zero

$$E_{min} \geq 0 \qquad (3)$$

The next constraint (4) deduces on the limit on number of base stations. Locations selected should not exceed as there are only M base stations available. The variable loc_j is a binary variable which will hold only values {0, 1}.This will be set to 1 if the mobile base station is located at point j, else it will hold 0. The sum of this loc_j should be smaller or equal to M to indicate that only M base stations are existing.

$$\sum_{0 \leq j \leq K} loc_j = M \qquad (4)$$

Constraint (5) says that the variable loc_j is a binary variable which will hold only values {0, 1}.

$$loc_j \in \{0,1\} 0 \leq j < T \qquad (5)$$

The finalized Integer linear programming formulation takes the following form which maximizes the minimum residual energy

Max E_{min}

Subject to

$$\sum_{k \in N(i)} g_{ki} + g_i = \sum_{j \in N(i)} g_{ij} \;\; 0 \leq i \leq N \qquad (1)$$

$$E_i - (E_{Tr} \sum_{j \in N(i)} g_{ij} + E_R \sum_{k \in N(i)} g_{ki}) \geq E_{min}, 0 \leq i \leq N \quad (2)$$

$$E_{min} \geq 0 \qquad (3)$$

$$\sum_{0 \leq j \leq K} loc_j = M \qquad (4)$$

$$loc_j \in \{0,1\} \leq j < T \qquad (5)$$

5. EXPERIMENTAL RESULTS

Simulation experiments are carried out using MATLAB to assess the performance of the proposed ILP model. The proposed model is compared with another kind of approach where the base stations are positioned arbitrarily in the sensing area and are assumed to be immobile. The Integer Linear Programming formulation is solved by using LINDO. The energy consumption model employed for simulation is the first order radio model. It assumes a simple model where to transmit a k-bit message for a distance d the radio expends

ETr(d, k)= k × (eelec + eamp× dα) (6)

ERc(k) = k ×eelec (7)

Where eamp and α is the energy spent by the transmission amplifier for one bit of data and the path-loss exponent respectively. In our experimental setup the value of d is set to 10 m, eelec is set to 50 nJ/bit,eamp is set to 0.1 nJ/bit/m2, and α is set to 2. The size of the packet is considered to be 512 bits. The initial energy of the sensor node is set to 0.1 Joules. Data generation is considered to be uniformly distributed. Simulations are done with network size of 100 and 200 nodes. The following type of simulation patterns are considered for extracting the experimental results.

- The first pattern presumes the base station is to be a static one and without loss of generality, it is positioned in the geographical center of the network.
- In the second pattern, the base stations are positioned at optimal locations which areproduced by the proposed Integer Linear Programming formulation.

The proposed work experimented with a maximum count of five base stations. Firstly, simulation experiments are done for the pattern where the base stations are assumed to be static. The experimental results are analyzed to extract the total number of rounds the base station is able to sustain until the death of one single node and it is also noted the number of rounds until the death of 10 percentage of the sensor nodes. In the next set, the base station is presumed to be mobile. The base stations are located at the optimal spots generated by the proposed integer linear programming model. The proposed work define the network lifetime in terms of number of rounds of the base station. The lifetime is measured for both static sink category and ILP formulation model.

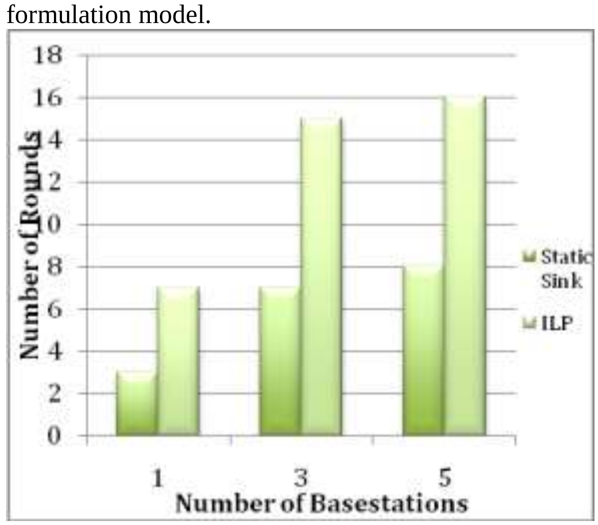

Figure 2: Network Lifetime with 100 Sensor nodes

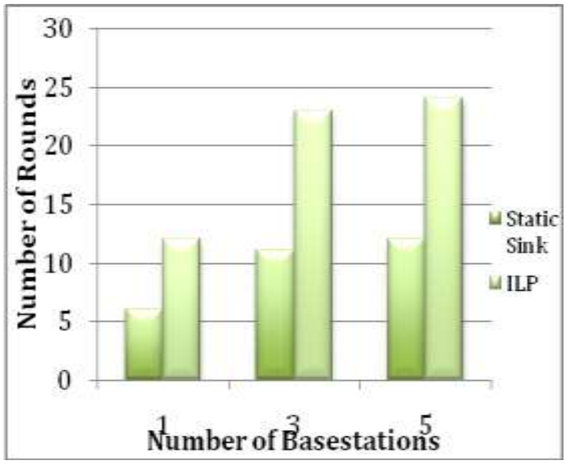

Figure 3: Network Lifetime with 200 Sensor nodes

The evaluation is demonstrated in the graphs (Figure 2 and Figure 3). Experimental results prove that the proposed Integer Linear Programming formulation achieves twice the amount of lifetime in comparison with the conventional static model for base stations.Similarly the average energy depletion of the sensor nodes for variable number of base stations are experimented for both the categories (static ad mobile)static as well as mobile base station categories. Apparently, it is noticed that, deploying mobile base station achieves very low energy consumption in comparison with the static base station model. Similarly the energy consumption of nodesin 100 size and 200size is also studied.It is noticed that energy consumption is more in static base stations where as it is considerably less in mobile base stations. Also it is noted that the energy consumption keeps decreasing on increase in the number of mobile base stations in the network.

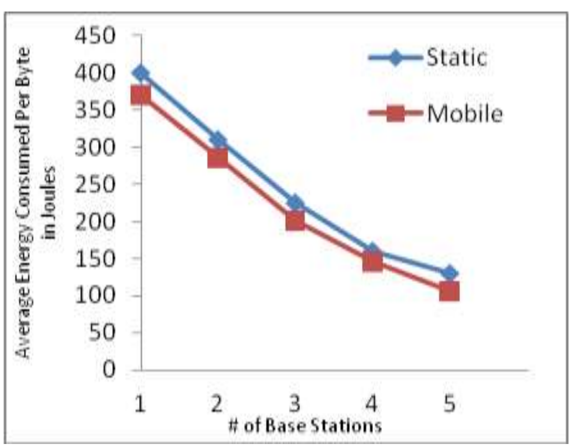

Figure 4: Energy consumption in network with 100 nodes

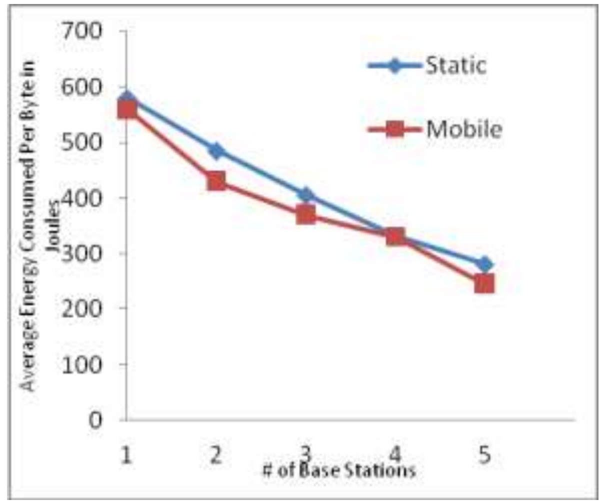

Figure 5: Energy consumption in Network with 200 nodes

This clearly says deploying multiple mobile base stations minimizes the energy consumption thereby increasing the network lifetime. This is illustrated in Figure 4 and Figure 5.The lifetime of the network is defined from a different kind of perspective in our simulation experiments. The network lifetime is measured in terms of number of rounds the base stations until at the least 10% of sensor nodes deplete their minimum energy level.The results are inferred by letting the base station to move until the specific percentage of sensor nodes completely depletes their energy levels. Simulation results are demonstrated in the graphs (Figure 4 and Figure 5) which indicate a very good enhancement in the network lifetime in the mobile that there is a steady rise in network lifetime for both static as well as mobile base station category.

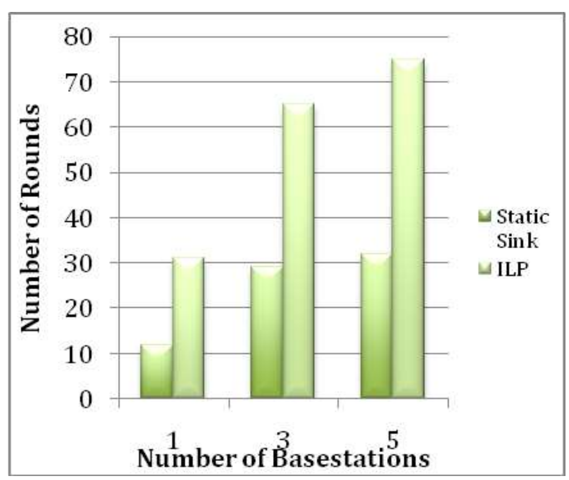

Figure 10 : Network Lifetime with 100 Sensor nodes (Until the expiry of 10 % of sensor nodes)

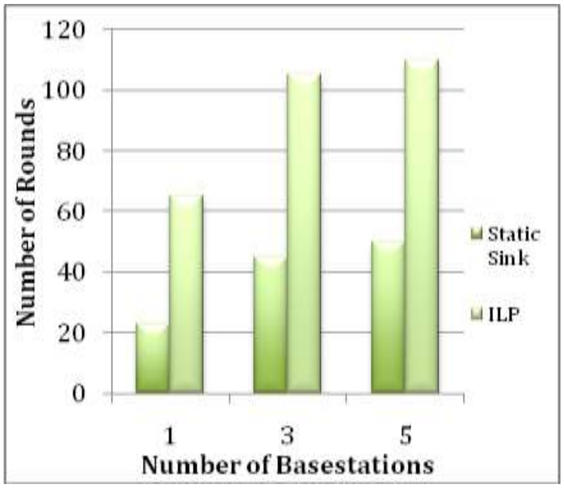

Figure 11: Network Lifetime with 100 Sensor nodes (Until the expiry of 10 % of sensor nodes)

6. CONCLUSION

It is observed from the simulation results that deploying multiple mobile base stations will decrease the average energy consumption of sensor nodes across the network. This leads a significant improvement in the network lifetime. Mobile entities deployed in the network are able to achieve twice the amount of improvement when compared to static entities.

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